

EL902647327 US

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICATION FOR LETTERS PATENT

* * * * *

Semiconductor Processing Workpiece Support With
Sensory Subsystem for Detection of Wafers or
Other Semiconductor Workpieces

* * * * *

INVENTOR

Kyle M. Hanson

4492P1022US

ATTORNEY'S DOCKET NO. ~~SE10-0140~~
~~(97-0024)~~

109250"448T5H50

Fig. 9 is an isometric view of the operator base and operator arm of the apparatus of the present invention with the protective cover removed.

Fig. 10 is a right side elevation view of the operator arm of the present invention showing the processing head pivot drive mechanism.

Fig. 11 is a left side elevation view of the operator arm of the present invention showing the operator arm drive mechanism.

Fig. 12 is schematic plan view of the operator arm indicating the portions detailed in Figs. 13 and 14.

Fig. 13 is a partial sectional plan view of the right side of the operator arm showing the processing head drive mechanism.

Fig. 14 is a partial sectional plan view of the left side of the operator arm showing the operator arm drive mechanism.

Fig. 15 is a side elevational view of a semiconductor workpiece holder constructed according to a preferred aspect of the invention.

Fig. 16 is a front sectional view of the Fig. 1 semiconductor workpiece holder.

Fig. 17 is a top plan view of a rotor which is constructed in accordance with a preferred aspect of this invention, and which is taken along line 3-3 in Fig. 16.

Fig. 18 is an isolated side sectional view of a finger assembly constructed in accordance with a preferred aspect of the invention and which is configured for mounting upon the Fig. 17 rotor.

Fig. 19 is a side elevational view of the finger assembly of Fig. 18.

Fig. 20 is a fragmentary cross-sectional enlarged view of a finger assembly and associated rotor structure.

Fig. 21 is a view taken along line 7-7 in Fig. 4 and shows a portion of the preferred finger assembly moving between an engaged and disengaged position.

Fig. 22 is a view of a finger tip of the preferred finger assembly and shows an electrode tip in a retracted or disengaged position (solid lines) and an engaged position (phantom lines) against a semiconductor workpiece.

Fig. 23 is a sectional view showing a second embodiment semiconductor processing station having a workpiece support assembly and a plating station bowl assembly.

Fig. 24 is an enlarged sectional view similar to Fig. 23 showing only portions of the workpiece support.

Fig. 25 is an exploded perspective view of portions of the workpiece support shown in Fig. 24.

Fig. 26 is an exploded perspective view of portions of a rotor assembly forming part of the workpiece support shown in Fig. 24.

Fig. 27 is a perspective view showing an interior face of the rotor assembly.

Fig. 28 is a perspective view showing the interior face of the rotor assembly with a wafer supported thereon.

1 Fig. 29 is an enlarged perspective view showing an actuator
2 transmission which mounts on the rotor assembly and controls motion
3 of workpiece-engaging fingers.

4 Fig. 30 is an exploded perspective assembly view of the actuator
5 transmission shown in Fig. 29.

6 Fig. 31 is a longitudinal sectional view of the actuator transmission
7 shown in Fig. 29.

8 Fig. 32 is a longitudinal sectional view of one preferred form of
9 electrode assembly which can be used in the second embodiment
10 processing system.

11 Fig. 33 is a longitudinal sectional view of one preferred form of
12 electrode assembly which can be used in the second embodiment
13 processing system.

14 Fig. 34 is a longitudinal sectional view of one preferred form of
15 electrode assembly which can be used in the second embodiment
16 processing system.

17 Fig. 35 is a longitudinal sectional view of one preferred form of
18 electrode assembly which can be used in the second embodiment
19 processing system.

20 Fig. 36 is a longitudinal sectional view of one preferred form of
21 electrode assembly which can be used in the second embodiment
22 processing system.
23
24

1 Fig. 37 is a sectional view showing an enlarged distal tip portion
2 of a further electrode before being pre-conditioned in accordance with
3 another aspect of the invention.

4 Fig. 38 is a sectional view showing the enlarged distal tip portion
5 of the previous figure after being pre-conditioned.

6 Fig. 39 is a longitudinal sectional view of one preferred form of
7 electrode assembly which can be used in the second embodiment
8 processing system.

9 Fig. 40 is a sectional view showing the electrode assembly of
10 Fig. 39 in position ready to engage a semiconductor workpiece.

11 Fig. 41 is a sectional view showing the electrode assembly of
12 Fig. 39 in an engaged position with a semiconductor workpiece.

13 Fig. 42 is a longitudinal sectional view showing the plating station
14 bowl shown in Fig. 23.

15 16 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

17 This disclosure of the invention is submitted in furtherance of the
18 constitutional purposes of the U.S. Patent Laws "to promote the
19 progress of science and useful arts" (Article 1, Section 8).
20
21
22
23
24

TABLE 1

Listing of Subsections of Detailed Description and
Pertinent Items with Reference Numerals and Page Numbers

Workpiece Support	11	rotate belt tensioner 439	18
semiconductor processing machine 400	11	tensioner hub 468	18
workpiece supports 401	11	processing head shaft bearing 440	18
Workpiece support 402	11	processing head rotate bearing 469	18
Workpiece support 403	11	processing head shaft bearing 441	18
semiconductor manufacturing chamber		cable brackets 442 and 443	19
404	11	rotate overtravel protect 444	19
beam emitter 81	11	rotate flag 447	20
operator base 405	11	Rotate optical switches 445 and 446	20
processing head 406	11		
operator arm 407	11	Operator Arm-Lift Mechanism	20
wafer holder 408	11	operator arm lift mechanism 448	20
fingers 409	11	lift motor shaft 454	21
Workpiece holder 408	11	lift gear drive 453	21
workpiece spin axis 410	11	lift drive shaft 456	21
process pivot axis 411	11	lift bushing 449	21
operator pivot axis 412	12	anchor plate 458	21
workpiece W	12	anchor fasteners 457	21
fingertips 414	12	Lift bearing 450	21
processing bowl 417	12	lift bearing support 460	22
left and right forks 418 and 419	13	operator arm frame 461	22
		lift anchor 451	22
Operator Base	14	lift overtravel protect 462	22
operator base back portion 420	14	lift optical switch low 463	23
operator base left yoke arm 421	14	lift optical switch high 464	23
operator base right yoke arm 422	14	lift flag 465	23
yoke arm fasteners 423	14	lift motor encoder 455	23
operator arm bearings 424	14	lift motor 452	23
operator arm 425	14	slotted lift flag mounting slots 467	23
		lift flag fasteners 466	23
Operator Arm	14		
process arm rear cavity 426	15	Processing Head	24
lift motor 452	15	processing head housing 470	24
rotate motor 428	15	circumferential grooves 471	24
processing head left pivot shaft 429	15	rotate shaft openings 474 and 475	24
processing head right pivot shaft 430	15	left and right processing head mounts	
		472	24
Operator Arm-Processing Head Rotate		processing head door 476	24
Mechanism	15	processing head void 477	25
Processing head rotate mechanism 431	16		
rotate shaft 432	16	Processing Head Spin Motor	25
securing collar 433	16	workpiece holder 478	25
rotate motor support 434	16	spin axis 479	25
rotate encoder 435	16	spin motor 480	26
rotate pulley inboard bearing 436	17	top motor housing 481	26
rotate belt 437	17	spin motor shaft 483	26
processing head pulley 438	17	workpiece holder rotor 484	26

1	rotor hub 485	26	angled slot 832a	38
	rotor hub recess 486	26	finger assembly frame outer flange 834	38
2	workpiece shaft snap-ring 488	26	inner drive plate portion 836	38
	rotor recess groove 489	26		
	spin encoder 498	27	Finger Assembly Drive System	38
3	optical tachometer 499	27	bearing 838	39
			collet 840	39
4	Processing Head Finger Actuators	29	bearing receptacle 839	39
	Pneumatic piston 502	30	spring 842	39
5	actuator spring 505	30	spring seat 844	39
	cavity end cap 507	30		
	retaining ring 508	30	Finger Assembly Electrical System	40
6	pneumatic inlet 503	30	pin connector 846	40
	pneumatic supply line 504	30	finger 848	40
7	actuator plate 509	30	nut 850	40
	actuator plate connect screw 510	30	anti-rotation pin 852	40
8	Wave springs 529	30	finger tip 854	41
	bushing 512	30	electrode contact 858	41
	pneumatic piston recess 511	30		
9	finger actuator contacts 513	31	Finger Assembly Drive System Interface	41
			finger actuator 862	41
10	Processing Head Workpiece Holder	31	actuation ring 863	42
	finger actuator lever 514	31	first movement path axis 864	42
11	finger stem 515	32	secondary linkage 865	42
	finger diaphragm 519	32	link arm 867	42
12	workpiece holder rotor 484	32	actuator torque ring 869	42
	finger opening 521	32	pneumatic operator 871	42
	rotor diaphragm lip 523	32		
13	finger spring 520	32	Engaged and Disengaged Positions	43
	finger actuator tab 522	32	arrow A	44
14	finger collar or nut 517	32	workpiece standoff 865	44
	shoulder 518	32	bend 866	45
15	finger actuator mechanism 500	33		
	cavity 501	33	Finger Assembly Seal	45
16	Semiconductor Workpiece Holder -		seal 868	45
	Electroplating Embodiment	33	rim portion 870	45
17	semiconductor workpiece holder 810	33		
	bottom half or bowl 811	34	Methods and Operation	47
18	Processing Head and Processing Head			
	Operator	34	Second Embodiment Processing Station -	
19	workpiece support 812	34	Generally	52
	spin head assembly 814	34	second semiconductor processing station	
20	lift/rotate assembly 816	34	900	52
	motor 818	35	workpiece support assembly 901	53
21	rotor 820	35	processing bowl 917	53
	rotor spin axis 822	35	processing or manufacturing chamber	
22	finger assembly 824	36	904	53
	actuator 825	36	Workpiece Support Generally	53
	rotor center piece 826	36	rotor assembly 984	53
23	spokes 828	36		
	rotor perimeter piece 830	36	Workpiece Support Head Operator	53
24	Finger Assembly	37	processing head 906	53
	finger assembly frame 832	38	head operator 907	53
			upper portion 908	53
			head connection shaft 909	53

1	horizontal pivot axis 910	53	workpiece standoff supports 721	63
2	Workpiece Support Main Part	54	finger actuator transmission 960	64
3	processing head housing 970	54	finger head mounting receptacle 954	64
4	processing head frame 982	54	locking pin groove 955	64
5	door plate 983	54	finger mounting pin 956	64
6	door ring member 984	54	transmission base 961	64
7	frame-pivot shaft connection 985	54	mounting cutout 962	64
8	pivot shaft connection base 935	55	transmission shaft 963	65
9	first housing part 971	55	shaft channel or groove 964	65
10	housing cap 972	55	shaft camming control member 965	65
11	main part mechanism chamber 973	55	ball 966	65
12	peripheral groove 986	55	ball support fastener 967	65
13	inflatable door seal 987	55	interior shaft passageway 968	65
14	annular rotor receiving groove 988	55	spring retainer 969	65
15	Workpiece Support Rotor Drive	56	finger mounting spring 938	65
16	workpiece spin motor 980	56	set screw 939	66
17	stator armatures 916	56	transmission head 656	66
18	motor shaft 918	56	bearing 657	66
19	bottom motor bearing 921	56	head pieces 658 and 659	66
20	bottom motor housing 922	56	head fasteners 660	66
21	top motor housing 923	56	head guide rods 661	66
22	top motor bearing 927	56	two guide passageways 662	66
23	fasteners 924	57	head bias springs 664	66
24	frame extensions 925	57	shaft seal 667	66
	top frame piece 926	57	transmission head depression ring 683	66
	Workpiece Support Rotor Assembly	57	operator output connection ring 684	66
	rotor assembly 930	57	pneumatic actuator engines 691	67
	rotor shaft 931	57	pneumatic manifolds 692	67
	rotor shaft hub 932	57	Electrode Fingers With Submerged	
	shaft hub receptacle 933	57	Conductive Current Transfer Areas	67
	inner rotor part 934	57	finger assembly 631	67
	inner rotor part hub 935	57	finger shaft 632	67
	peripheral band 936	57	finger head 633	67
	snap-ring 937	57	locking pin 956	67
	transmission receptacles 937	57	dielectric sheathing 634 and 635	68
	fasteners 941	58	contact head 636	68
	rotor face panel 943	58	contact face 637	68
	apertures 787	58	submersion line 639	68
	support standoffs 721	58	first electrically conductive segment 642	68
	workpiece peripheral guide pins 722	58	second electrically conductive segment	
	reinforcing ribs 942	58	643	68
	side wall 944	58	third electrically conductive segment 644	69
	finger passageways 949	59	third dielectric segment 653	69
	rotor shaft mounting nut 888	59	third dielectric sheath 654	69
	angular position encoder 498	59	distal contact insert part 655	70
	Workpiece Detection Subsystem	60	insert receptacle 616	70
	mounting 738	61	contact face 617	70
	detector 739	61	electrode finger 979	70
	workpiece detector windows 741	61	dielectric sheath 621	70
	Workpiece Support Finger Actuator	63	Electrode Fingers With Dielectric Sheaths	
	finger pivot axes 953	63	Covering Submerged Areas	72
			electrode finger 681	72
			dielectric sheath 682	72
			contact insert side walls 619	72

1	insert contact part or tip 655	72
2	Pre-Conditioning of Electrode Contact	
	Faces	73
	electrode 614	73
3	distal exposed surface 615	73
	dielectric sheath 616	74
4	Methods Using Workpiece-Engaging	
	Electrode Assembly With Sealing Boot	75
5	electrode finger 583	75
	electrode shaft 584	75
6	head 633	75
	cover or boot 585	75
7	distal contact lip 586	76
	contact insert part 655	76
8	skirt-portion 587	76
	electrode shaft distal end surface 588	76
9	contact face 617	76
	substrate or other subjacent layer 561	76
10	thin metallic seed layer 562	76
	via or other opening 563	76
	photoresist layer 564	76
11	Plating Bowl Assembly	
	electroplating bowl assembly 303	79
12	process bowl or plating vessel 316	79
	outer bowl side wall 617	79
13	bowl bottom 319	79
	bowl rim assembly 314	79
14	cup assembly 320	79
	fluid cup portion 321	79
15	cup side 322	79
	cup bottom 323	79
	flutes 372	79
16	cup main joint 387	80
	riser tube 361	80
17	fitting 362	80
	fluid inlet line 325	80
18	bowl bottom opening 327	80
	cup fluid inlet openings 324	80
	overflow chamber 345	80
19	level detectors 351 and 352	81
	diffuser height adjustment mechanisms	
20	386	82
	mounting fasteners 389	82
21	Plating Anode Shield	
	anode shield 393	82
22	anode shield fasteners 394	82

* * * (End of Table 1) * * *

Workpiece Support

Turning now to Fig. 1, a semiconductor processing machine 400 having two workpiece supports 401 is shown. Workpiece support 402 is shown in a "open" or "receive wafer" position in order to receive a workpiece or semiconductor wafer for further processing. Workpiece support 403 is shown in a "closed" or "deployed" position wherein the semiconductor wafer has been received by the workpiece support and is being exposed to the semiconductor manufacturing process in the semiconductor manufacturing chamber 404. Fig. 1 also shows an optional beam emitter 81 for emitting a laser beam detected by robotic wafer conveyors to indicate position of the unit.

Turning now to Fig. 2, an enlarged view of the workpiece support 401 is shown. Workpiece support 401 advantageously includes operator base 405, a processing head 406, and an operator arm 407. Processing head 406 preferably includes workpiece holder or wafer holder 408 and which further includes fingers 409 for securely holding the workpiece during further process and manufacturing steps. Workpiece holder 408 more preferably spins about workpiece spin axis 410.

The processing head is advantageously rotatable about processing head pivot axis or, more briefly termed, process pivot axis 411. In this manner, a workpiece (not shown) may be disposed between and grasped by the fingers 409, at which point the processing head is preferably rotated about process head pivot axis 411 to place the workpiece in a position to be exposed to the manufacturing process.

In the preferred embodiment, operator arm 407 may be pivoted about operator pivot axis 412. In this manner, the workpiece is advantageously lowered into the process bowl (not shown) to accomplish a step in the manufacture of the semiconductor wafer.

Turning now to Figs. 3-5, the sequence of placing a workpiece on the workpiece support and exposing the workpiece to the semiconductor manufacturing process is shown. In Fig. 3, a workpiece *W* is shown as being held in place by fingertips 414 of fingers 409. Workpiece *W* is grasped by fingertips 414 after being placed in position by robot or other means.

Once the workpiece *W* has been securely engaged by fingertips 414, processing head 406 can be rotated about process head pivot axis 411 as shown in Fig. 4. Process head 406 is preferably rotated about axis 411 until workpiece *W* is at a desired angle, such as approximately horizontal. The operator arm 407 is pivoted about operator arm pivot axis 412 in a manner so as to coordinate the angular position of processing head 406. In the closed position, the processing head is placed against the rim of bowl 416 and the workpiece *W* is essentially in a horizontal plane. Once the workpiece *W* has been secured in this position, any of a series of various semiconductor manufacturing process steps may be applied to the workpiece as it is exposed in the processing bowl 417.

Since the processing head 406 is engaged by the operator arm 407 on the left and right side by the preferably horizontal axis 411

Operator Base

Turning now to Fig. 9, operator base 405 is shown. The present invention advantageously includes an operator base 405 which forms an essentially yoke-shaped base having an operator base back portion 420, an operator base left yoke arm 421, and an operator base right yoke arm 422. Yoke arms 421 and 422 are securely connected to the base of the yoke 420. In the preferred embodiment, the yoke arms are secured to the yoke base by the yoke arm fasteners 423. The yoke arm base in turn is advantageously connected to the semiconductor process machine 400 as shown in Fig. 1.

The upper portions of the yoke arm advantageously include receptacles for housing the operator arm bearings 424 which are used to support the pivot shafts of the operator arm 425, described more fully below.

Operator Arm

Still viewing Fig. 9, the present invention advantageously includes an operator arm 407. As described previously, operator arm 407 preferably pivots about the operator arm pivot axis 412 which connects the center line defined by the centers of operator arm pivot bearings 424.

Operator arm or pivot arm 407 is advantageously constructed in such a manner to reduce mass cantilevered about operator arm pivot

axis 412. This allows for quicker and more accurate positioning of the pivot arm as it is moved about pivot arm axis 412.

The left fork of the pivot arm 418, shown more clearly in Fig. 11, houses the mechanism for causing the pivot arm to lift or rotate about pivot arm pivot axis 412. Pivot arm right fork 419, shown more clearly in Fig. 10, houses the mechanism for causing the processing head 406 (not shown) to rotate about the process head pivot axis 411.

The process arm rear cavity 426, shown in Fig. 9, houses the lift motor 452 for causing the operator arm 407 to rotate about pivot arm axis 412. Process arm rear cavity 426 also houses rotate motor 428 which is used to cause the processing head 406 to rotate about the processing head pivot axis 411. The rotate motor 428 may more generally be described as a processing head pivot or rotate drive. Processing head 406 is mounted to operator arm 407 at processing head left pivot shaft 429 and processing head right pivot shaft 430.

Operator arm 407 is securely attached to left yoke arm 421 and right yoke arm 422 by operator arm pivot shafts 425 and operator arm pivot bearings 424, the right of which such bearing shaft and bearings are shown in Fig. 9.

Operator Arm-Processing Head Rotate Mechanism

Turning now to Fig. 13, a sectional plan view of the right rear corner of operator arm 407 is shown. The right rear section of operator arm 407 advantageously contains the rotate mechanism which

is used to rotate processing head 406 about processing head pivot shafts 430 and 429. Processing head rotate mechanism 431 preferably consists of rotate motor 428 which drives rotate shaft 432, more generally described as a processing head drive shaft. Rotate shaft 432 is inserted within rotate pulley 425 which also functions as the operator arm pivot shaft. As described previously, the operator arm pivot shaft/lift pulley is supported in operator arm pivot bearings 424, which are themselves supported in operator base yoke arm 422. Rotate shaft 432 is secured within left pulley 424 by securing collar 433. Securing collar 433 secures rotate pulley 425 to rotate shaft 432 in a secure manner so as to assure a positive connection between rotate motor 428 and rotate pulley 425. An inner cover 584 is also provided.

Rotate motor 428 is disposed within process arm rear cavity 426 and is supported by rotate motor support 434. Rotate motor 428 preferably is a servo allowing for accurate control of speed and acceleration of the motor. Servo motor 428 is advantageously connected to rotate encoder 435 which is positioned on one end of rotate motor 428. Rotate encoder 435, more generally described as a processing head encoder, allows for accurate measurement of the number of rotations of rotate motor 428, as well as the position, speed, and acceleration of the rotate shaft 432. The information from the rotate encoder may be used in a rotate circuit which may then be used to control the rotate motor when the rotate motor is a servo. This information is useful in obtaining the position and rate of travel of the

processing head, as well as controlling the final end point positions of the processing head as it is rotated about process head rotate axis 411.

The relationship between the rotate motor rotations, as measured by rotate encoder 435, may easily be determined once the diameters of the rotate pulley 425 and the processing head pulley 438 are known. These diameters can be used to determine the ratio of rotate motor relations to processing head rotations. This may be accomplished by a microprocessor, as well as other means.

Rotate pulley 425 is further supported within operator arm 407 by rotate pulley inboard bearing 436 which is disposed about an extended flange on the rotate pulley 425. Rotate pulley inboard bearing 436 is secured by the body of the operator arm 407, as shown in Fig. 13.

Rotate pulley 425 advantageously drives rotate belt 437, more generally described as a flexible power transmission coupling. Referring now to Fig. 10, rotate belt 437 is shown in the side view of the right arm 419 of the operator arm 407. Rotate belt 437 is preferably a toothed timing belt to ensure positive engagement with the processing head drive wheel, more particularly described herein as the processing head pulley 438, (not shown in this view). In order to accommodate the toothed timing belt 437, both the rotate pulley 425 and the processing head pulley 438 are advantageously provided with gear teeth to match the tooth pattern of the timing belt to assure positive engagement of the pulleys with the rotate belt.

Rotate mechanism 431 is preferably provided with rotate belt tensioner 439, useful for adjusting the belt to take up slack as the belt may stretch during use, and to allow for adjustment of the belt to assure positive engagement with both the rotate pulley and the processing head pulley. Rotate belt tensioner 439 adjusts the tension of rotate belt 437 by increasing the length of the belt path between rotate pulley 425 and processing head pulley 438, thereby accommodating any excess length in the belt. Inversely, the length of the belt path may also be shortened by adjusting rotate belt tensioner 439 so as to create a more linear path in the upper portion of rotate belt 437. The tensioner 439 is adjusted by rotating it about tensioner hub 468 and securing it in a new position.

Turning now to Fig. 13, processing head pulley 438 is mounted to processing head rotate shaft 430 in a secured manner so that rotation of processing head pulley 438 will cause processing head rotate shaft 430 to rotate. Processing head shaft 430 is mounted to operator arm right fork 419 by processing head shaft bearing 440, which in turn is secured in the frame of the right fork 419 by processing head rotate bearing 469. In a like manner, processing head shaft 429 is mounted in operator arm left fork 418 by processing head shaft bearing 441, as shown in Fig. 9.

Processing head pivot shafts 430 and 429 are advantageously hollow shafts. This feature is useful in allowing electrical, optical, pneumatic, and other signal and supply services to be provided to the

processing head. Service lines such as those just described which are routed through the hollow portions of processing head pivot shafts 429 and 430 are held in place in the operator arms by cable brackets 442 and 443. Cable brackets 442 and 443 serve a dual purpose. First, routing the service lines away from operating components within the operator arm left and right forks. Second, cable brackets 442 and 443 serve a useful function in isolating forces imparted to the service cables by the rotating action of processing head 406 as it rotates about processing head pivot shafts 429 and 430. This rotating of the processing head 406 has the consequence that the service cables are twisted within the pivot shafts as a result of the rotation, thereby imparting forces to the cables. These forces are preferably isolated to a particular area so as to minimize the effects of the forces on the cables. The cable brackets 442 and 443 achieve this isolating effect.

The process head rotate mechanism 431, shown in Fig. 13, is also advantageously provided with a rotate overtravel protect 444, which functions as a rotate switch. Rotate overtravel protect 444 preferably acts as a secondary system to the rotate encoder 435 should the control system fail for some reason to stop servo 428 in accordance with a predetermined position, as would be established by rotate encoder 435. Turning to Fig. 13, the rotate overtravel protect 444 is shown in plan view. The rotate overtravel protect preferably consists of rotate optical switches 445 and 446, which are configured to correspond to the extreme (beginning and end point) portions of the processing head, as

well as the primary switch component which preferably is a rotate flag 447. Rotate flag 447 is securely attached to processing head pulley 438 such that when processing head shaft 430 (and consequently processing head 406) are rotated by virtue of drive forces imparted to the processing head pulley 425 by the rotate belt 437, the rotate flag 447 will rotate thereby tracking the rotate motion of processing head 406. Rotate optical switches 445 and 446 are positioned such that rotate flag 447 may pass within the optical path generated by each optical switch, thereby generating a switch signal. The switch signal is used to control an event such as stopping rotate motor 428. Rotate optical switch 445 will guard against overtravel of processing head 406 in one direction, while rotate optical switch 446 will provide against overtravel of the processing head 406 in the opposite direction.

Operator Arm-Lift Mechanism

Operator arm 407 is also advantageously provided with an operator arm lift mechanism 448 which is useful for causing the operator arm to lift, that is, to pivot or rotate about operator arm pivot axis 412. Turning to Fig. 14, the operator arm lift mechanism 448 is shown in the sectional plan view of the right rear corner of operator arm 407.

Operator arm lift mechanism 448 is advantageously driven by lift motor 452. Lift motor 452 may be more generally described as an operator arm drive or operator arm pivot drive. Lift motor 452 is

preferably a servo motor and is more preferably provided with an operator encoder, more specifically described as lift motor encoder 456. When lift motor 452 is a servo motor coupled with lift encoder 456, information regarding the speed and absolute rotational position of the lift motor shaft 454 may be known from the lift encoder signal. Additionally, by virtue of being a servo mechanism, the angular speed and acceleration of lift motor 452 may be easily controlled by use of the lift signal by an electrical circuit. Such a lift circuit may be configured to generate desired lift characteristics (speed, angle, acceleration, etc.). Fig. 14 shows that the lift operator may also include a brake 455 which is used to safely stop the arm if power fails.

Lift motor 452 drives lift motor shaft 454 which in turn drives lift gear drive 453. Lift gear drive 453 is a gear reduction drive to produce a reduced number of revolutions at lift drive shaft 456 as the function of input revolutions from lift motor shaft 454.

Lift drive gear shaft 456 is secured to lift anchor 451 which is more clearly shown in Fig. 11. Lift anchor 451 is preferably shaped to have at least one flat side for positively engaging lift bushing 449. Lift anchor 451 is secured to lift drive shaft 456 by anchor plate 458 and anchor fasteners 457. In this manner, when lift drive shaft 456 is rotated, it will positively engage lift bushing 449. Returning to Fig. 14, it is seen that lift bushing 449 is mounted in operator left yoke arm 421, and is thus fixed with respect to operator base 405. Lift bearing 450 is disposed about the lift bushing shank and is supported in

operator arm 407 by lift bearing support 460 which is a bushing configured to receive lift bearing 450 on a first end and to support lift gear drive 453 on a second end. Lift bearing support 460 is further supported within operator arm 407 by operator arm frame 461. The lift arm is thus free to pivot about lift bushing 449 by virtue of lift bearing 450.

In operation, as lift motor 452 causes lift gear drive 453 to produce rotations at gear drive shaft 456, lift anchor 451 is forced against lift bushing 449 which is securely positioned within right operator yoke arm 421. The reactive force against the lift anchor 451 will cause lift bearing support 460 to rotate relative to lift bushing 449. Since lift bushing 449 is fixed in operator base 405, and since operator base 405 is fixed to processing machine 400, rotation of lift bearing support 460 will cause lift arm 407 to pivot about operator arm pivot axis 412, thereby moving the processing head 406. It is advantageous to consider the gear drive shaft (or "operator arm shaft") as being fixed with respect to operator base 405 when envisioning the operation of the lift mechanism.

Operator lift mechanism 448 is also advantageously provided with a lift overtravel protect 462 or lift switch. The lift rotate protect operates in a manner similar to that described for the rotate overtravel protect 444 described above. Turning now to Fig. 11, a left side view of the operator arm 407 is shown which shows the lift overtravel protect in detail.

Processing Head

Turning now to Fig. 6, a front elevation schematic view of the processing head 406 is shown. Processing head 406 is described in more detail in Figs. 7 and 8. Turning now to Fig. 7, a sectional view of the left front side of processing head 406 is shown. Processing head 406 advantageously includes a processing head housing 470 and frame 582. Processing head 406 is preferably round in shape in plan view allowing it to easily pivot about process head pivot axis 411 with no interference from operator arm 407, as demonstrated in Figs. 3-5. Returning to Fig. 7, processing head housing 470 more preferably has circumferential grooves 471 which are formed into the side of process head housing 470. Circumferential grooves 471 have a functional benefit of increasing heat dissipation from processing head 406.

The sides of processing head housing 470 are advantageously provided with rotate shaft openings 474 and 475 for receiving respectively left and right processing head pivot shafts 429 and 430. Processing head pivot shafts 429 and 430 are secured to the processing head 406 by respective left and right processing head mounts 472 and 473. Processing head mounts 472 and 473 are affirmative connected to processing head frame 582 which also supports processing head door 476 which is itself securely fastened to processing head housing 470. Consequently, processing head pivot shafts 429 and 430 are fixed with respect to processing head 407 and may therefore rotate or pivot with respect to operator arm 407. The details of how processing head pivot

Turning to Fig. 8, spin motor 480 has armatures 526 which drive spin motor shaft 483 in rotational movement to spin workpiece holder 478. Spin motor 480 is supported by bottom motor bearing 492 in bottom motor housing 482. Bottom motor housing 482 is secured to processing head 406 by door 476. Spin motor 480 is thus free to rotate relative to processing head housing 470 and door 476. Spin motor 480 is preferably additionally held in place by top motor housing 481 which rests on processing head door 476. Spin motor 480 is rotationally isolated from top motor housing 481 by top motor bearing 493, which is disposed between the spin motor shaft 483 and top motor housing 481.

The spin motor is preferably an electric motor which is provided with an electrical supply source through pivot shaft 429 and/or 430. Spin motor 480 will drive spin motor shaft 483 about spin axis 479.

To secure workpiece holder rotor 484 to spin motor shaft 483, workpiece holder rotor 484 is preferably provided with a rotor hub 485. Rotor hub 485 defines a rotor hub recess 486 which receives a flared end of workpiece holder shaft 491. The flared end 487 of workpiece holder shaft 491 is secured within the rotor hub recess 486 by workpiece shaft snap-ring 488 which fits within rotor recess groove 489 above the flared portion 487 of workpiece holder shaft 491.

The workpiece holder shaft 491 is fitted inside of spin motor shaft 483 and protrudes from the top of the spin motor shaft. The top of workpiece holder shaft 491 is threaded to receive thin nut 527

(see Fig. 7). Thin nut 527 is tightened against optical tachometer 499 (describe more fully below). Optical tachometer 499 is securely attached to spin motor shaft 483 such that as the spin motor 480 rotationally drives the spin motor shaft 483, the workpiece holder shaft 491 is also driven.

Workpiece holders may be easily changed out to accommodate various configurations which may be required for the various processes encountered in manufacturing of the semiconductors. This is accomplished by removing spin encoder 498 (described below), and then thin nut 527. Once the thin nut has been removed the workpiece holder 478 will drop away from the processing head 406.

The processing head is also advantageously provided with a spin encoder 498, more generally described as a workpiece holder encoder, and an optical tachometer 499. As shown in Fig. 7, spin encoder 498 is mounted to top motor housing 481 by encoder support 528 so as to remain stationary with respect to the processing head 406. Optical tachometer 499 is mounted on spin motor shaft 483 so as to rotate with the motor 480. When operated in conjunction, the spin encoder 498 and optical tachometer 499 allow the speed, acceleration, and precise rotational position of the spin motor shaft (and therefore the workpiece holder 478) to be known. In this manner, and when spin motor 480 is provided as a servo motor, a high degree of control over the spin rate, acceleration, and rotational angular position of the workpiece with respect to the process head 407 may be obtained.

In one application of the present invention the workpiece support is used to support a semiconductor workpiece in an electroplating process. To accomplish the electroplating an electric current is provided to the workpiece through an alternate embodiment of the fingers (described more fully below). To provide electric current to the finger, conductive wires are run from the tops of the fingers inside of the workpiece holder 478 through the electrode wire holes 525 in the flared lower part of workpiece holder shaft 491. The electrode wires are provided electric current from electrical lines run through processing pivot shaft 429 and/or 430.

The electrical line run through pivot shaft 430/429 will by nature be stationary with respect to processing head housing 470. However, since the workpiece holder rotor is intended to be capable of rotation during the electroplating process, the wires passing into workpiece support shaft 491 through electrode wire holes 525 may rotate with respect to processing head housing 470. Since the rotating electrode wires within workpiece shaft 491 and the stationary electrical supply lines run through pivot shaft 430/429 must be in electrical communication, the rotational/stationary problem must be overcome. In the preferred embodiment, this is accomplished by use of electrical slip ring 494.

Electrical slip ring 494, shown in Fig. 7, has a lower wire junction 529 for receiving the conductive ends of the electrical wires passing into workpiece holder shaft 491 by electrode wire holes 525. Lower wire

1 junction 529 is held in place within workpiece holder shaft 491 by
 2 insulating cylindrical collar 497 and thus rotates with spin motor shaft
 3 483. The electrode wires terminate in a single electrical contact 531
 4 at the top of the lower wire junction 529. Electrical slip ring 494
 5 further has a contact pad 530 which is suspended within the top of
 6 workpiece holder shaft 491. Contact pad 530 is mechanically fastened
 7 to spin encoder 493, which, as described previously, remains stationary
 8 with respect to processing head housing 470. The stationary-to-rotational
 9 transition is made at the tip of contact pad 530, which is in contact
 10 with the rotating electrical contact 531. Contact pad 530 is electrically
 11 conductive and is in electrical communication with electrical contact 531.
 12 In the preferred embodiment, contact pad 530 is made of
 13 copper-beryllium. A wire 585 carries current to finger assemblies when
 14 current supply is needed, such as on the alternative embodiment
 15 described below.

16 17 Processing Head Finger Actuators

18 Workpiece holder 478, described more fully below, advantageously
 19 includes fingers for holding the workpiece *W* in the workpiece holder,
 20 as shown in Figs. 7 and 8. Since the workpiece holder 478 may be
 21 removed as described above, it is possible to replace one style of
 22 workpiece holder with another. Since a variety of workpiece holders
 23 with a variety of fingers for holding the workpiece is possible, it is
 24 desirable to have a finger actuator mechanism disposed within processing

head 407 which is compatible with any given finger arrangement. The invention is therefore advantageously provided with a finger actuator mechanism.

Turning to Fig. 7, a finger actuator mechanism 500 is shown. Finger actuator mechanism 500 is preferably a pneumatically operated mechanism. A pneumatic cylinder is formed by a cavity 501 within top motor housing 481. Pneumatic piston 502 is disposed within cavity 501. Pneumatic piston 502 is biased in an upward position within cavity 501 by actuator spring 505. Actuator spring 505 is confined within cavity 501 by cavity end cap 507, which is itself constrained by retaining ring 508. Pneumatic fluid is provided to the top of pneumatic piston 502 via pneumatic inlet 503. Pneumatic fluid is provided to pneumatic inlet 503 by pneumatic supply line 504 which is routed through processing head pivot shaft 429 and hence through the left fork 418 of the operator arm 407. Turning to Fig. 8, it can be seen that a second pneumatic cylinder which is identical to the pneumatic cylinder just described is also provided.

Pneumatic piston 502 is attached to actuator plate 509 by actuator plate connect screw 510. Wave springs 529 provide flexibility to the connecting at screws 510. Actuator plate 509 is preferably an annular plate concentric with the spin motor 580 and disposed about the bottom motor housing 482, and is symmetrical about spin axis 479. Actuator plate 509 is secured against pneumatic piston 502 by bushing 512 which is disposed in pneumatic piston recess 511 about pneumatic piston 502

Bushing 512 acts as a support for wave springs 529 to allow a slight tilting of the actuator plate 509. Such an arrangement is beneficial for providing equal action against the finger actuator contracts 513 about the entire actuator plate or ring 509.

When pneumatic fluid is provided to the space above the pneumatic piston 502, the pneumatic piston 502 travels in a downward direction compressing actuator spring 505. As pneumatic piston 502 travels downward, actuator plate 509 is likewise pushed downward by flexible bushing 512. Actuator plate 509 will contact finger actuator contacts 513 causing the fingers to operate as more fully described below.

Actuator seals 506 are provided to prevent pneumatic gas from bypassing the top of the pneumatic piston 502 and entering the area occupied by actuator spring 505.

Processing Head Workpiece Holder

Workpiece holder 478 is used to hold the workpiece W , which is typically a semiconductor wafer, in position during the semiconductor manufacturing process.

Turning now to Fig. 8, a finger 409 is shown in cross section. Finger 409 advantageously includes a finger actuator contact 513 which is contacted by actuator plate 509, as described above. Finger actuator contact 513 is connected to finger actuator lever 514 (more generally, "finger extension") which is cantilevered from and connected to the

finger stem 515. Finger stem 515 is inserted into finger actuator lever 514. Disposed about the portion of the finger actuator lever which encompasses and secures finger stem 515 is finger diaphragm 519. Finger diaphragm 519 is preferably made of a flexible material such as Tetrafluoroethylene, also known as Teflon® (registered trademark of E. I. DuPont de Nemours Company). Finger 409 is mounted to workpiece holder rotor 484 using finger diaphragm 519. Finger diaphragm 519 is inserted into the finger opening 521 in rotor 484. The finger diaphragm 519 is inserted into the rotor from the side opposite that to which the workpiece will be presented. Finger diaphragm 519 is secured to rotor 484 against rotor diaphragm lip 523. Forces are intentionally imparted as a result of contact between the actuator plate 509 and the finger actuator contact 513 when the finger actuator mechanism 500 is actuated.

Finger actuator lever 514 is advantageously biased in a horizontal position by finger spring 520 which acts on finger actuator tab 522 which in turn is connected to finger actuator lever 514. Finger spring 520 is preferably a torsion spring secured to the workpiece holder rotor 484.

Finger stem 515 is also preferably provided with finger collar or nut 517 which holds the finger stem 515 against shoulder 518. Finger collar 517 threads or otherwise securely fits over the lower end of finger actuator lever 514. Below the finger collar 517, finger stem 515 extends for a short distance and terminates in fingertip 414. Fingertip

414 contains a slight groove or notch which is beneficially shaped to receive the edge of the workpiece *W*.

In actuation, finger actuator plate 509 is pushed downward by finger actuator mechanism 500. Finger actuator plate 509 continues its downward travel contacting finger actuator contacts 513. As actuator plate 509 continues its downward travel, finger actuator contacts are pushed in a downward direction. As a result of the downward direction, the finger actuator levers 514 are caused to pivot.

In the preferred embodiment, a plurality of fingers are used to hold the workpiece. In one example, six fingers were used. Once the actuator plate 509 has traveled its full extent, the finger stems 515 will be tilted away from the spin axis 479. The circumference described by the fingertips in this spread-apart position should be greater than the circumference of the workpiece *W*. Once a workpiece *W* has been positioned proximate to the fingertips, the pneumatic pressure is relieved on the finger actuator and the actuator spring 505 causes the pneumatic piston 502 to return to the top of the cavity 501. In so doing, the actuator plate 509 is retracted and the finger actuator levers are returned to their initial position by virtue of finger springs 520.

Semiconductor Workpiece Holder - Electroplating Embodiment

Fig. 15 is a side elevational view of a semiconductor workpiece holder 810 constructed according to a preferred aspect of the invention.

Workpiece holder 810 is used for processing a semiconductor

workpiece such as a semiconductor wafer shown in phantom at *W*. One preferred type of processing undertaken with workpiece holder 810 is a workpiece electroplating process in which a semiconductor workpiece is held by workpiece holder 810 and an electrical potential is applied to the workpiece to enable plating material to be plated thereon. Such can be, and preferably is accomplished utilizing a processing enclosure or chamber which includes a bottom half or bowl 811 shown in phantom lines in Fig. 1. Bottom half 811 together with workpiece holder 810 forms a sealed, protected chamber for semiconductor workpiece processing. Accordingly, preferred reactants can be introduced into the chamber for further processing. Another preferred aspect of workpiece holder 810 is that such moves, rotates or otherwise spins the held workpiece during processing as will be described in more detail below.

Processing Head and Processing Head Operator

Turning now to Fig. 15, semiconductor workpiece holder 810 includes a workpiece support 812. Workpiece support 812 advantageously supports a workpiece during processing. Workpiece support 812 includes a processing head or spin head assembly 814. Workpiece support 812 also includes a head operator or lift/rotate assembly 816. Spin head assembly 814 is operatively coupled with lift/rotate assembly 816. Spin head assembly 814 advantageously enables a held workpiece to be spun or moved about a defined axis during

processing. Such enhances conformal coverage of the preferred plating material over the held workpiece. Lift/rotate assembly 816 advantageously lifts spin head assembly 814 out of engagement with the bottom half 811 of the enclosure in which the preferred processing takes place. Such lifting is preferably about an axis x_1 . Once so lifted, lift/rotate assembly 816 also rotates the spin head and held workpiece about an axis x_2 so that the workpiece can be presented face-up and easily removed from workpiece support 812. In the illustrated and preferred embodiment, such rotation is about 180° from the disposition shown in Fig. 15. Advantageously, a new workpiece can be fixed or otherwise attached to the workpiece holder for further processing as described in detail below.

The workpiece can be removed from or fixed to workpiece holder 810 automatically by means of a robotically controlled arm. Alternatively, the workpiece can be manually removed from or fixed to workpiece holder 810. Additionally, more than one workpiece holder can be provided to support processing of multiple semiconductor workpieces. Other means of removing and fixing a semiconductor workpiece are possible.

Fig. 16 is a front sectional view of the Fig. 15 semiconductor workpiece holder. As shown, workpiece support 812 includes a motor 818 which is operatively coupled with a rotor 820. Rotor 820 is advantageously mounted for rotation about a rotor spin axis 822 and serves as a staging platform upon which at least one finger assembly

824 is mounted. Preferably, more than one finger assembly is mounted on rotor 820, and even more preferably, four or more such finger assemblies are mounted thereon and described in detail below although only two are shown in Fig. 16. The preferred finger assemblies are instrumental in fixing or otherwise holding a semiconductor workpiece on semiconductor workpiece holder 810. Each finger assembly is advantageously operatively connected or associated with a actuator 825. The actuator is preferably a pneumatic linkage which serves to assist in moving the finger assemblies between a disengaged position in which a workpiece may be removed from or added to the workpiece holding, and an engaged position in which the workpiece is fixed upon the workpiece holder for processing. Such is described in more detail below.

Fig. 17 is a top or plan view of rotor 820 which is effectively taken along line 3-3 in Fig. 16. Fig. 16 shows the preferred four finger assemblies 824. As shown, rotor 820 is generally circular and resembles from the top a spoked wheel with a nearly continuous bottom surface. Rotor 820 includes a rotor center piece 826 at the center of which lies rotor axis 822. A plurality of struts or spokes 828 are joined or connected to rotor center 826 and extend outwardly to join with and support a rotor perimeter piece 830. Advantageously, four of spokes 828 support respective preferred finger assemblies 824. Finger assemblies 824 are advantageously positioned to engage a semiconductor workpiece, such as a wafer *W* which is shown in phantom lines in the

position such would occupy during processing. When a workpiece is so engaged, it is fixedly held in place relative to the rotor so that processing can be effected. Such processing can include exposing the workpiece to processing conditions which are effective to form a layer of material on one or more surfaces or portions of a wafer or other workpiece. Such processing can also include moving the workpiece within a processing environment to enhance or improve conformal coverage of a layering material. Such processing can, and preferably does include exposing the workpiece to processing conditions which are effective to form an electroplated layer on or over the workpiece.

Finger Assembly

Referring now to Figs. 18-20, various views of a preferred finger assembly are shown. The preferred individual finger assemblies are constructed in accordance with the description below. Fig. 18 is an isolated side sectional view of a finger assembly constructed in accordance with a preferred aspect of the invention. Fig. 19 is a side elevational view of the finger assembly turned 90° from the view of Fig. 18. Fig. 20 is a fragmentary cross-sectional enlarged view of a finger assembly and associated rotor structure. The finger assembly as set forth in Figs. 18 and 19 is shown in the relative position such as it would occupy when processing head or spin head assembly 814 (Figs. 15 and 16) is moved or rotated by head operator or lift/rotate assembly 816 into a position for receiving a semiconductor workpiece. The finger

SECRET-44-06300

1 assembly between engaged and disengaged positions. The finger
2 assembly drive system includes a bearing 838 and a collet 840
3 operatively adjacent the bearing. Bearing 838 includes a bearing
4 receptacle 839 for receiving a pneumatically driven source, a fragmented
5 portion of which is shown directly above the receptacle in Fig. 20.
6 The pneumatically driven source serves to longitudinally reciprocate and
7 rotate collet 840, and hence a preferred portion of finger assembly 824.
8 A preferred pneumatically driven source is described below in more
9 detail in connection with the preferred longitudinal and rotational
10 movement effectuated thereby. Such longitudinal reciprocation is
11 affected by a biasing mechanism in the form of a spring 842 which is
12 operatively mounted between finger assembly frame 832 and a spring
13 seat 844. The construction develop a bias between finger assembly
14 frame 832 and spring seat 844 to bias the finger into engagement
15 against a wafer. Advantageously, the cooperation between the above
16 mentioned pneumatically driven source as affected by the biasing
17 mechanism of the finger assembly drive system, enable collet 840 to be
18 longitudinally reciprocated in both extending and retracting modes of
19 movement. As such, finger assembly 824 includes a biased portion
20 which is biased toward a first position and which is movable to a
21 second position away from the first position. Other manners of
22 longitudinally reciprocating the finger assembly are possible.

23
24

1 Finger Assembly Electrical System

2 Referring to Figs. 16 and 19, the finger assembly preferably
3 includes a finger assembly electrical system which is utilized to
4 effectuate an electrical bias to a held workpiece and supply electrical
5 current relative thereto. The finger assembly electrical system includes
6 a pin connector 846 and a finger 848. Pin connector 846
7 advantageously provides an electrical connection to a power source (not
8 shown) via wire 585 and associate slip ring mechanism, described above
9 in connection with Fig. 7 and other Figs. This is for delivering an
10 electrical bias and current to an electrode which is described below.
11 Pin connector 846 also rides within angled slot 832a thereby
12 mechanically defining the limits to which the finger assembly may be
13 both longitudinally and rotationally moved.

14 Finger 848 is advantageously fixed or secured to or within collet
15 840 by a nut 850 which threadably engages a distal end portion of
16 collet 840 as shown best in Fig. 18. An anti-rotation pin 852
17 advantageously secures finger 848 within collet 840 and prevents relative
18 rotation therebetween. Electrical current is conducted from connector
19 846 through collet 840 to finger 860, all of which are conductive, such
20 as from stainless steel. The finger and collet can be coated with a
21 suitable dielectric coating 856, such as TEFLON or others. The collet
22 840 and finger member 860 are in one form of the invention made
23 hollow and tubular to conduct a purge gas therethrough.

Finger assembly 824 may also optionally include a distal tip or finger tip 854. Tip 854 may also have a purge gas passage formed therethrough. Finger tip 854 advantageously engages against a semiconductor workpiece (see Fig. 20) and assists in holding or fixing the position of the workpiece relative to workpiece holder 810. Finger tip 854 also assists in providing an operative electrical connection between the finger assembly and a workpiece to which an electrical biased is to be applied and through which current can move. Finger tip 85 can include an electrode contact 858 for electrically contacting a surface of a semiconductor workpiece once such workpiece is secured as describe below.

Finger Assembly Drive System Interface

A finger assembly drive system interface is operatively coupled with the finger assembly drive system to effectuate movement of the finger assembly between the engaged and disengaged positions. A preferred finger assembly drive system interface is described with reference to Figs. 16 and 20. One component of the finger assembly drive system interface is a finger actuator 862. Finger actuator 862 is advantageously provided for moving the finger assembly between the engaged and disengaged position. Finger actuator 862 acts by engaging bearing receptacle 839 and moving finger assembly 824 between an engaged position and a disengaged position. In the engaged position,

1 finger tip 854 is engaged against a semiconductor workpiece. In the
2 disengaged position finger tip 854 is moved away from the workpiece.

3 The finger assembly drive system interface includes pneumatic
4 actuator 825 (Fig. 16). Pneumatic actuators 825 are operatively
5 connected to an actuation ring 863 and operates thereupon causing the
6 drive plate to move reciprocally in the vertical direction as viewed in
7 Fig. 16. Finger actuator 862 is operatively connected to actuation ring
8 863 in a manner which, upon pneumatic actuation, moves the finger
9 actuator into engagement with bearing receptacle 839 along the dashed
10 line in Fig. 20. Such allows or enables the finger assembly to be
11 moved longitudinally along a first movement path axis 864.

12 Pneumatic actuator linkage 825 also includes a secondary linkage
13 865. Secondary linkage 865 is pneumatic as well and includes a link
14 arm 867. Link arm 867 is connected or joined to an actuator torque
15 ring 869. Preferably, torque ring 869 is concentric with rotor 820 (Fig.
16 17) and circuitously links each of the finger actuators together. A
17 pneumatic operator 871 is advantageously linked with the secondary
18 linkage 865 for applying force and operating the linkage by angularly
19 displacing torque ring 869. This in turn rotates the finger assemblies
20 into and away from the engaged position.

21 Preferably finger actuator engagement bits 862, under the influence
22 of pneumatic linkage 825, moves the finger assembly, and more
23 specifically collet 840 and finger 848 along a first axial movement path
24 along axis 864. The finger actuator engagement bits 862, then under

the influence of pneumatic operator 871 are turned about the axes of each bit like a screwdriver. This moves collet 840 and finger 848 in a second angular movement. Such second movement turns the fingers sufficiently to produce the angular displacement shown in Fig. 21. According to a preferred aspect of this invention, such movement of the finger assemblies between the engaged and disengaged positions takes place when spin head assembly 814 has been moved 180° from its Fig. 15 disposition into a face-up condition.

The engagement bits 862 can be provided with a purge gas passage therethrough. Gas is supplied via tube 893 and is passed through the finger assemblies.

Engaged and Disengaged Positions

Fig. 21 is a view of a portion of a finger assembly, taken along line 7-7 in Fig. 18. Such shows in more detail the above-described engaged and disengaged positions and movement therebetween relative to a workpiece *W*. In the disengaged position, finger 848 is positioned adjacent the semiconductor workpiece and the finger tip and electrode contact do not overlap with workpiece *W*. In the engaged position, the finger tip overlaps with the workpiece and the electrode is brought to bear against the workpiece. From the disengaged position, finger assembly 824, upon the preferred actuation, is moved in a first direction away from the disengaged position. Preferably, such first direction is longitudinal and along first movement path axis 864. Such longitudinal

1 movement is linear and in the direction of arrow A as shown in Figs.
2 18 and 19. The movement moves the finger assembly to the position
3 shown in dashed lines in Fig. 18. Such movement is effectuated by
4 pneumatic operator 825 which operates upon actuation ring 863 (Fig.
5 16). This in turn, causes finger actuator 862 to engage with finger
6 assembly 824. Such linear movement is limited by angled slot 832a.
7 Thereafter, the finger assembly is preferably moved in a second
8 direction which is different from the first direction and preferably
9 rotational about the first movement path axis 864. Such is illustrated
10 in Fig. 21 where the second direction defines a generally arcuate path
11 between the engaged and disengaged positions. Such rotational
12 movement is effectuated by secondary linkage 865 which pneumatically
13 engages the finger actuator to effect rotation thereof. As so moved,
14 the finger assembly swings into a ready position in which a
15 semiconductor workpiece is ready to be engaged and held for
16 processing. Once the finger assembly is moved or swung into place
17 overlapping a workpiece, the preferred finger actuator is spring biased
18 and released to bear against the workpiece. An engaged workpiece is
19 shown in Fig. 20 after the workpiece has been engaged by finger tip
20 854 against a workpiece standoff 865, and spin head assembly 814 has
21 been rotated back into the position shown in Fig. 15. Such preferred
22 pneumatically assisted engagement takes place preferably along movement
23 path axis 864 and in a direction which is into the plane of the page
24 upon which Fig. 21 appears.

As shown in Fig. 18, finger 848 extends away from collet 840 and preferably includes a bend 866 between collet 840 and finger tip 854. The preferred bend is a reverse bend of around 180° which serves to point finger tip 854 toward workpiece *W* when the finger assembly is moved toward or into the engaged position (Fig. 21). Advantageously, the collet 840 and hence finger 848 are longitudinally reciprocally movable into and out of the engaged position.

Finger Assembly Seal

The finger assembly preferably includes a finger assembly seal 868 which is effectuated between finger 848 and a desired workpiece when the finger assembly is moved into the engaged position. Preferably, adjacent finger tip 854. A seal 868 is mounted adjacent electrode contact 858 and effectively seals the electrode contact therewithin when finger assembly 824 is moved to engage a workpiece. The seal can be made of a suitable flexible, preferably elastomeric material, such as VITON.

More specifically, and referring to Fig. 22, seal 868 can include a rim portion 870 which engages workpiece surface *W* and forms a sealing contact therebetween when the finger assembly is moved to the engaged position. Such seal advantageously isolates finger electrode 860 from the processing environment and materials which may plate out or otherwise be encountered therein. Seal 868 can be provided with an

optional bellows wall structure 894 (Fig. 22), that allows more axial flexibility of the seal.

Fig. 22 shows, in solid lines, seal 868 in a disengaged position in which rim portion 870 is not engaged with workpiece *W*. Fig. 22 also shows, in phantom lines, an engaged position in which rim portion 870 is engaged with and forms a seal relative to workpiece *W*. Preferably and advantageously, electrode contact 858 is maintained in a generally retracted position within seal 868 when the finger assembly is in the disengaged position. However, when the finger assembly is moved into the engaged position, seal 868 and rim portion 870 thereof splay outwardly or otherwise yieldably deform to effectively enable the electrode and hence electrode contact 858 to move into the engaged position against the workpiece. One factor which assists in forming the preferred seal between the rim portion and the workpiece is the force which is developed by spring 842 which advantageously urges collet 840 and hence finger 860 and finger tip 858 in the direction of and against the captured workpiece. Such developed force assists in maintaining the integrity of the seal which is developed in the engaged position. Another factor which assists in forming the preferred seal is the yieldability or deformability of the finger tip when it is brought into contact with the workpiece. Such factors effectively create a continuous seal about the periphery of electrode contact 858 thereby protecting it from any materials, such as the preferred plating materials which are used during electroplate processing.

Methods and Operation

In accordance with a preferred processing aspect of the present invention, and in connection with the above-described semiconductor workpiece holder, a sheathed electrode, such as electrode 860, is positioned against a semiconductor workpiece surface in a manner which permits the electrode to impart a voltage bias and current flow to the workpiece to effectuate preferred electroplating processing of the workpiece. Such positioning not only allows a desired electrical bias to be imparted to a held workpiece, but also allows the workpiece itself to be mechanically held or fixed relative to the workpiece holder. That is, finger assembly 824 provides an electrical/mechanical connection between a workpiece and the workpiece holder as is discussed in more detail below.

Electrode 856 includes an electrode tip or electrode contact 858 which engages the workpiece surface. A seal is thus formed about the periphery of the electrode tip or contact 858 so that a desired electrical bias may be imparted to the workpiece to enable plating material to be plated thereon. According to a preferred aspect of the processing method, the electrode is moved in a first direction, preferably longitudinally along a movement axis, away from a disengaged position in which the workpiece surface is not engaged by the electrode tip or contact 858. Subsequently, the electrode is rotated about the same movement axis and toward an engaged position in which the electrode tip may engage, so as to fix, and thereafter bias the workpiece surface.

1 Such preferred movement is effectuated by pneumatic linkage 825 and
2 pneumatic operator 871 as described above.

3 According to a preferred aspect of the invention, the seal which
4 is effectuated between the electrode member and the workpiece is
5 formed by utilizing a yieldable, deformable seal member 868 which
6 includes a rim portion 870. The rim portion 870 serves by contacting
7 the workpiece surface to form a continuous seal as shown in Fig. 8.
8 The preferred electrode tip is brought into engagement with the
9 workpiece surface by advancing the electrode tip from a retracted
10 position within the seal or other sheath to an unretracted position in
11 which the workpiece surface is engaged thereby. Such movement of the
12 electrode tip between the retracted and unretracted positions is
13 advantageously accommodated by the yieldable features of the seal 868.

14 In addition to providing the preferred electrical contact between
15 the workpiece and the electrode tip, the finger assembly also forms a
16 mechanical contact or connection between the assembly and the
17 workpiece which effectively fixes the workpiece relative to the workpiece
18 holder. Such is advantageous because one aspect of the preferred
19 processing method includes rotating the workpiece about rotor axis 822
20 while the workpiece is exposed to the preferred plating material. Such
21 not only ensures that the electrical connection and hence the electrical
22 bias relative to the workpiece is maintained during processing, but that
23 the mechanical fixation of the workpiece on the workpiece holder is
24 maintained as well.

The above described pneumatically effectuated movement of the preferred finger assemblies between the engaged and disengaged positions is but one manner of effectuating such movement. Other manners of effectuating such movement are possible.

The invention also includes novel methods for presenting a workpiece to a semiconductor process. In such methods, a workpiece is first secured to a workpiece holder. The methods work equally well for workpiece holders known in the art and for the novel workpiece holders disclosed herein.

In the next step in the sequence, the workpiece holder is rotated about a horizontal axis from an initial or first position where the workpiece holder was provided with the workpiece to a second position. The second position will be at an angle to the horizontal. The angle of the workpiece holder to the horizontal is defined by the angle between the plane of the workpiece and the horizontal. In the method, the workpiece holder is advantageously suspended about a second horizontal axis which is parallel to the first horizontal axis of the workpiece holder. At this point in the method, the angle between the first and second horizontal axes and a horizontal plane corresponds to the angle between the workpiece holder and the horizontal. The workpiece holder is then pivoted about the second horizontal axis to move the workpiece and the workpiece holder from its initial location to a final location in a horizontal plane. Advantageously, when the

SECRET 06501

1 workpiece holder is pivoted about the second horizontal axis, the first
2 horizontal axis also pivots about the second horizontal axis.

3 Preferably, during the step of rotating the workpiece holder about
4 the first horizontal axis, the angle of the workpiece holder with respect
5 to some known point, which is fixed with respect to the workpiece
6 holder during the rotation process, is continually monitored. Monitoring
7 allows for precise positioning of the workpiece holder with respect to
8 the horizontal surface.

9 Likewise, during pivoting of the workpiece holder about the
10 second horizontal axis, it is preferable that the angle defined by the
11 line connecting the first and second horizontal axes and the horizontal
12 plane be continually monitored. In this manner, the absolute position
13 of the workpiece holder (and hence the workpiece itself) will be known
14 with respect to the horizontal plane. This is important since the
15 horizontal plane typically will contain the process to which the
16 workpiece will be exposed.

17 It should be noted that in the above and following description,
18 while the workpiece is described as being presented to a horizontal
19 plane, it is possible that the workpiece may also be presented to a
20 vertical plane or a plane at any angle between the vertical and the
21 horizontal. Typically, the processing plane will be a horizontal plane
22 due to the desire to avoid gravitational effects on process fluids to
23 which the workpiece is exposed. In one embodiment after the
24 workpiece has been presented to the processing plane, the workpiece

holder is rotated about a spin axis to cause the workpiece to spin in the horizontal plane. Although not required in all semiconductor manufacturing processes, this is a common step which may be added in the appropriate circumstance.

The next advantageous step in the method consists of pivoting the workpiece holder about the second horizontal axis back along the path that the workpiece holder was initially pivoted along when presenting the workpiece to the horizontal process plane. There is no requirement that the workpiece holder be pivoted back to the same position whence it began, although doing so may have certain advantages as more fully described below.

The method advantageously further consists of the step of rotating the workpiece holder about the first horizontal axis to return the workpiece to the position when it was initially presented to and engaged by the workpiece holder. It is advantageous to rotate the workpiece holder about the first axis in a direction opposite from the initial rotation of the workpiece holder.

The advantage of having the workpiece holder terminate at an end position which corresponds to the initial position when the workpiece was loaded into the workpiece holder is efficiency. That is, additional machine movements are not required to position the workpiece holder to receive a new workpiece.

The method more preferably includes the step of rotating the workpiece holder about the first horizontal axis at least two support

1 points along the first horizontal axis. This beneficially provides support
2 and stability to the workpiece holder during the rotation process and
3 subsequent movement of the apparatus.

4 The method also more preferably includes the step of pivoting the
5 workpiece holder along with the first horizontal axis about the second
6 horizontal axis at least two support points along the second horizontal
7 axis. This beneficially provides additional support for the workpiece
8 holder while allowing the workpiece holder to be moved in a vertical
9 or "Z-axis" direction.

10 Importantly, the only motion described in the above method is
11 rotational motion about several axes. In the method described, there
12 is no translational motion of the workpiece holder in a X-, Y-, or Z-
13 axis without corresponding movement in another axis as a result of
14 rotating through an arc.

15 16 **Second Embodiment Processing Station - Generally**

17 Fig. 23 shows principal components of a second semiconductor
18 processing station 900 incorporating features of the invention.
19 Processing station 900 as shown is specifically adapted and constructed
20 to serve as an electroplating station similar to electroplating station 400
21 described hereinabove. To reduce unnecessary replication, only the
22 principal parts showing differences and features of the invention are
23 shown and described. Other aspects of the invention are as described
24 above or can be done in a variety of constructions.

1 The two principal parts of processing station 900 are the
2 workpiece support assembly 901 and the processing bowl 917. The
3 workpiece support 401 will be considered first and the processing bowl
4 and its features will be described in further detail later in this
5 description. As Fig. 23 indicates, portions of the workpiece support 401
6 mate with the processing bowl to provide a substantially closed
7 processing vessel which encloses a substantially enclosed processing or
8 manufacturing chamber 904.

9 10 **Workpiece Support Generally**

11 The workpiece support processing head holds a wafer W for
12 rotation within the processing chamber 904. A rotor assembly 984 has
13 a plurality of workpiece-engaging fingers 979 that hold the wafer against
14 features of the rotor. Fingers 979 are also preferably adapted to
15 conduct current between the wafer and a plating electrical power supply
16 (not shown).

17 18 **Workpiece Support Head Operator**

19 The workpiece support assembly 901 includes a processing head
20 906 which is supported by an head operator 907. Head operator 907
21 includes an upper portion 908 which is adjustable in elevation to allow
22 height adjustment of the processing head. Head operator 907 also has
23 a head connection shaft 909 which is operable to pivot about a
24 horizontal pivot axis 910. Pivotal action of the processing head using

operator 907 allows the processing head to be placed in an open or face-up position (not shown) for loading and unloading wafer W. Fig. 23 shows the processing head pivoted into a face-down position in preparation for processing.

A variety of suitable head operators which provide both elevational and horizontal pivoting action are possible for use in this system. The preferred operators are also fitted with positional encoders (not shown) which indicate both the elevation of the processing head and its angular position as pivoted about horizontal head pivot axis 910.

Workpiece Support Main Part

Figs. 24 and 25 show additional details of the preferred construction of processing head 906. The processing head includes a main part which moves with and is relatively stationary with respect to the pivot shaft 909. The main part supports a rotating assembly which will be described in greater detail below.

The main part includes a processing head housing 970 and processing head frame 982. The processing head frame 982 includes a door plate 983. A door ring member 984 is joined to plate 983 using suitable fasteners to provide a door assembly which serve as the principal parts covering the upper opening of the processing bowl when the processing head is mated with the bowl.

The processing head frame also includes a frame-pivot shaft connection 985 which includes two mounting rings which receive and

1 securely connect with the processing head pivot shaft 909. Fig. 25
2 shows that the pivot shaft connection mounting rings are made in two
3 parts and secured by fasteners (not shown). The pivot shaft connection
4 base 935 is secured to the door plate 983 using fasteners.

5 Processing head 906 is generally round in shape when viewed in
6 plan view. The processing head main part includes a housing 970
7 which has a first housing part 971 and a second housing part or
8 housing cap 972. The processing head housing 970 encloses a main
9 part enclosure which surrounds a processing head main part mechanism
10 chamber 973. Chamber 973 is used to house additional processing head
11 components, such as the spin motor, the finger actuators, and related
12 service lines, such as discussed more fully below.

13 The upper surface of the door ring member 984 is provided with
14 a groove which receives the lower edge of the first housing piece 971.
15 The outer periphery of the door ring member also advantageously
16 includes a peripheral groove 986 which mounts an inflatable door
17 seal 987. Seal 987 seals with portions of the processing bowl to form
18 a more fluid-tight processing chamber therewithin.

19 The lower surface of the door ring member 984 is preferably
20 provided with an annular rotor receiving groove 988 which receives top
21 peripheral portions of the rotor therein in close proximity. This
22 construction allows a gas purge (not shown) to be applied between the
23 door and rotor to help prevent processing vapors from migrating behind
24 the rotor and into to the various mechanisms present in the main part

TOP SECRET 44-6860

1 of the processing head. The periphery of the door ring member is
2 further provided with a chamfered lower edge to facilitate mating with
3 the processing bowl.

4 The processing head also advantageously includes a moving
5 assembly in the form of a workpiece holder 978. The workpiece holder
6 includes fingers 979 for holding a semiconductor workpiece. These
7 features will be more fully described below.

8 9 Workpiece Support Rotor Drive

10 The processing head main part also includes a workpiece holder
11 drive which moves the workpiece holder relative to the main part of
12 the processing head. The preferred action is for the workpiece holder
13 drive to be in the form of a rotor drive which rotates the workpiece
14 holder. The rotor drive can be an electric motor, pneumatic motor or
15 other suitable drive. As shown, the processing head includes an electric
16 workpiece spin motor 980.

17 The drive motor 980 has stator armatures 916 which drive motor
18 shaft 918 in rotational movement. Drive motor 980 is supported by
19 bottom motor bearing 921 in bottom motor housing 922. Bottom motor
20 housing 922 is secured to the main part of the processing head at a
21 central opening in the door plate 983. Motor 980 is also held in place
22 by a top motor housing 923. Drive motor 980 is rotationally isolated
23 from top motor housing 923 by a top motor bearing 927, which is
24 disposed between the spin motor shaft 918 and the top motor housing.

Both motor housings are secured to the processing head frame 982 using fasteners 924 which extend down through the motor housings and into the door plate 983. The fasteners 924 also extend upwardly through frame extensions 925. Frame extensions 925 support a top frame piece 926. Cap 972 is screwed onto piece 926 at mating threads along the lower interior portion of the cap.

The drive motor is preferably an electric motor provided with a supply of electricity via wiring run through pivot shaft 909 or otherwise extending to the processing head.

Workpiece Support Rotor Assembly

The hollow shaft 918 of the drive motor receives portion of a rotor assembly therein. The rotor assembly is secured to the motor shaft and is rotated therewith. Fig. 26 shows major portions of the rotor assembly in exploded detail. The rotor assembly 930 includes a rotor shaft 931. Rotor shaft 931 has a rotor shaft hub 932 which is held within a shaft hub receptacle 933 formed in an inner rotor part 934. The inner or first rotor part 934, also called an inner rotor drive plate, has a plurality of spokes which extend from the inner rotor part hub 935 outwardly to connect with a peripheral band 936. The shaft hub 932 is held in the hub receptacle 933 using a snap-ring 937.

The inner rotor part 934 also includes a plurality of receptacles 937. Receptacles 937 are used to mount a plurality of actuator transmission assemblies 960. The transmission receptacles 937 receive

lower portions of the transmission assemblies. The receptacles have bottom openings through which the finger assemblies 979 (see Fig 24) extend and are mounted in the transmission assemblies. Additional description is provided below in connection with the finger assembly actuators.

Fig. 26 also shows that the rotor assembly 930 preferably includes a second or outer rotor part 940. The inner and outer rotor parts are secured together by fasteners 941 (see Fig. 24). The outer rotor part 940 includes a rotor face panel 943 which extends across the disk-shaped rotor part to form a barrier to processing fluids.

The front or exposed side of the outer rotor part is provided with apertures 787 through which finger actuator transmission shafts 963 extend in supporting relationship for the fingers 979. Workpiece support standoffs 721 are mounted upon the face of the rotor to support the back side of the workpieces in opposition to the forces exerted by the fingers 979. The face of the rotor can also advantageously be provided with workpiece peripheral guide pins 722 to facilitate proper location of a wafer upon installation upon the face of the rotor.

Along the back side of the outer rotor part are reinforcing ribs 942 which align with the spokes of the inner rotor part 934. The reinforcing ribs 942 receive fasteners 941 and connect the two rotor parts together. At the periphery of the outer rotor part is a side wall 944. The upper or back edge of the peripheral side wall 944 is in

close fitting relationship with the door ring 984 at annular groove 988 to resist migration of processing fluids to the back side of the rotor assembly.

The outer rotor part 940 also has an array of bosses 948 at the peripheral end of the reinforcing ribs 942. Within bosses 948 are finger passageways 949 which allow the finger assemblies 979 to mount in the finger actuator transmission assemblies 960. The rotor assembly also includes the transmission assemblies and finger assemblies. Additional details of these components as well as additional parts of the finger actuation mechanisms is described in greater detail below.

The rotor shaft 931 fits inside of motor shaft 918 and protrudes from the top of the shaft and is held by a rotor shaft mounting nut 888. Also mounted near the top of the rotor shaft is an optical tachometer 499. Optical tachometer 499 is securely attached to motor shaft 918 and features, such as notches, formed on the tachometer are optically detected to provide a precise measurement of rotor angular velocity. The optical emitter-detector coupler used with tachometer 499 are not shown, but are mounted on either sides of the wheel to allow selective passage of light therethrough.

The rotor assembly is also advantageously provided with a angular position encoder 498. As shown, encoder 498 is mounted to the top motor housing 923 so as to remain stationary with respect to the main part of the processing head. The angular position encoder 498 and optical tachometer 499 allow the speed, acceleration, and precise

1 rotational position of the motor shaft 918 and rotor assembly to be
2 known and controlled.

3 In one application of the present invention the workpiece support
4 is used to support a semiconductor workpiece in an electroplating
5 process. To accomplish the electroplating an electric current is provided
6 to the workpiece through an alternate embodiment of the fingers
7 (described more fully below). To provide electric current to the
8 electrode fingers 979, conductive wires (not shown) are run from the
9 transmissions 960 toward the hub of the rotor. Current is supplied to
10 the electrode fingers 979 through the hollow rotor shaft using wires (not
11 shown) connected to a slip ring electrical connector 687 mounted near
12 the upper end of shafts 918 and 931.

13 14 Workpiece Detection Subsystem

15 The processing head also preferably includes a wafer or workpiece
16 detection subsystem. This subsystem allows the processing head to
17 through its control system to determine whether there is a workpiece
18 held in the rotor or not. This is of particular significance if the
19 system experiences a power interruption or otherwise is being started
20 in any situation where workpieces may be present in the machine.
21 Operational safeguards can then be included in the control system to
22 prevent mishandling of wafers or processing stations which may have a
23 workpiece held therein.
24

As shown in Fig. 25, the processing head frame part 983 is provided with a mounting 738 which is an appropriately shaped recess used to mount a detector 739. Detector 739 is preferably an optical emitter-detector unit which emits a beam which passes downwardly as oriented in Fig. 25. The emitted beam passes through workpiece detector windows 741 (see Fig. 26) formed in the face panel of the outer rotor part. The windows can be discrete inserts, or more preferably, they are thinly dimensioned panel portions of the rotor face panel 943. The rotor face panel is advantageously made of a material which is transmissive of the detector beam being used. For example, the panel can be made from polyvinylidene fluoride polymer which is thinned to a suitably thin dimension, such as in the approximate range from about 1-5 millimeters.

A suitable detector 739 is a Sunx brand model RX-LS200, and other commercially available detectors. The preferred detector uses an infrared beam emitter (not individually shown) which is detected by a pair of beam detectors (not individually shown). The beam emitter and beam detectors are preferably part of the same unit which serves as the workpiece detector. The workpiece detector preferably operated in a trigonometric mode. In the trigonometric mode, the angle of the reflected beam is an important discriminating parameter. Thus any portion of the beam reflected by the detector window 741 is incident upon the pair of detectors at a reflection angle which is outside of the normal detection angle range. Such portions of the beam reflected by

1 the window 741 are thus minimized and the detector is not triggered
2 by such reflectance. Instead, the pair of beam detectors are adjusted
3 to sense a reflected beam which is incident at a reflected angle
4 associated with the wafer or other workpiece surface which is more
5 distant than the window. When there is no workpiece held in the
6 workpiece holder, then the detector senses the absence and this is used
7 by the control system as an indication that there is no wafer present
8 in the wafer support.

9 In general the emitted infrared beam used in the preferred
10 workpiece detector subsystem is sufficient to detect the presence of a
11 wafer or other semiconductor workpiece held in a stationary position
12 with the rotor positioned so that one of the windows 741 is in position
13 aligned to allow the emitted beam to pass therethrough and be reflected
14 by the workpiece back through the window for detection. The detection
15 system described herein is not sufficient to allow detection during
16 rotation of the rotor and any workpiece held thereon. The invention
17 may also be practiced in a situation where sensing can be accomplished
18 while the rotor rotates.

19 The workpiece detector arrangement shown has the distinct benefit
20 of being mounted wholly behind the rotor face panel without provision
21 of any openings which might allow processing fluids to enter the space
22 behind the rotor. This reduces maintenance, improves reliability, and
23 simplifies construction costs.
24

Workpiece Support Finger Actuator

The preferred wafer support also includes a plurality of wafer-engaging fingers 979 positioned about the periphery of the wafer or other workpiece. Fig. 27 shows the front face of the outer rotor part 940 in a face-up orientation with fingers 979 extending therefrom. The preferred fingers are J-shaped and mounted for pivotal action about a finger pivot axes 953. The pivotal action preferably ranges between an outboard position and an inboard position. In the outboard position the J-shaped fingers are positioned outwardly and clear of the wafer peripheral edge. A preferred outboard position is illustrated in Fig. 27. In the outboard position the hooked portions of the J-shaped fingers are oriented at approximately 15 angular degrees outward from a line drawn tangent to the periphery of the wafer adjacent to the finger. In the inboard position the fingers are positioned inwardly to engage the wafer, as shown in Fig. 28. In the inboard position the hooked portions of the J-shaped fingers are oriented at approximately 45 angular degrees inward from a line drawn tangent to the periphery of the wafer adjacent to the finger.

The face of the rotor assembly is provided with workpiece standoff supports 721 which are in complementary position to the engagement ends of the fingers when the fingers are in a retracted position to hold the wafer. This construction securely captures the wafer or other workpiece between the fingers and the standoffs.

In addition to the pivotal action of the engagement fingers, the fingers are also move axially toward and away from the face of the rotor. In the inboard position the fingers are retracted toward the wafer to engage the exposed, front face of the wafer along a marginal band adjacent to the periphery of the wafer. In the outboard position the fingers are extended away from the face of the wafer to prevent rubbing action as the fingers pivot away from the wafer. This compound action including both a pivot component and an axial component is accomplished using a finger actuator transmission 960 shown in perspective relationship to the rotor in Fig. 26. Transmissions 960 are mounted within the transmission receptacles 937 of the inner rotor part 934. The transmissions are further mounted by transmission retainers 951 which are secured by fasteners to inner rotor part 934.

Fig. 29 shows the finger actuator transmission 960 in greater detail. The lower end of transmission 960 includes a finger head mounting receptacle 954. Receptacle 954 is advantageously provided with a locking feature included to secure the fingers in the receptacles. As shown, the receptacle includes a convoluted, bayonet-type, locking pin groove 955. Locking pin groove 955 receives a transversely mounted finger mounting pin 956 (see Fig. 32) which is a rolled or other suitable pin secured in the head of the finger assembly.

Figs. 29, 30, and 31 detail the preferred construction of the actuator transmissions 960. The transmissions include a transmission base 961 which is provided with a mounting cutout 962 which is borne

upon by the retainers 951 when installed in the rotor. The base also includes a central passageway within which is received a transmission shaft 963. Shaft 963 can both pivot and move axially within the central passageway. The shaft and base 961 are constructed to interact in a manner which controls the relative motion of the shaft. This is done to provide the compound pivotal and axial movement of the shaft and a finger 979 which is held therein. As shown, the inactive mechanism is provided in the form of a shaft channel or groove 964 which is engaged by a shaft camming control member 965. The camming action of the groove is provide by a helical advance over a pivotal movement range of approximately 60 degrees of rotation. The associate axial travel is in the range of approximately 5-20 millimeters, more preferably about 10-15 millimeters.

The camming control member 965 is advantageously in the form of a ball 966 held into the groove 964 using a ball support fastener 967. Fastener 967 has a ball socket which receives portions of the ball. Fastener 967 also serves as a convenient electrical contact terminal when electricity is supplied to the fingers 979.

The shaft 963 is provided with an interior shaft passageway 968 which receives a spring retainer 969. Spring retainer 969 has an engagement head which mechanically engages with a finger mounting spring 938. The spring 938 serves to bias a finger assembly into a locked position using the locking pin 956 held in biased relationship by

1 groove 955. Spring retainer 969 is secured in the passageway by a set
2 screw 939.

3 Fig. 31 also shows that the transmission 960 preferably includes
4 a transmission head 656. Transmission head 656 is connected to the
5 upper end of shaft 963 using a bearing 657 which allows the shaft to
6 pivot relative to the head pieces 658 and 659. Head pieces 658 and
7 659 capture the bearing between them, and are joined by head fasteners
8 660. The head fasteners 660 thread into a pair of head guide rods
9 661. Head guide rods 661 are slidably received by two guide
10 passageways 662 formed in the transmission base 961. The head
11 assembly is biased upwardly by two head bias springs 664. Engagement
12 between ball 966 and groove 964 limits the upward movement of the
13 head assembly under action by springs 664.

14 The lower end of shaft 963 is sealed to the base 961 using a
15 shaft seal 667 which helps to keep any abraded metal within the
16 transmission and prevent contamination toward the fingers 979. Shaft
17 963 also has a transverse hole 665 which is used as an electrical
18 connection feature that receives a wire (not shown) run from the slip
19 ring down the rotor shaft. The wire is secured in hole 665 by a set
20 screw (not shown).

21 The transmissions 960 are activated by a transmission head
22 depression ring 683 (see Fig. 24). Depression ring 683 is connected to
23 an operator output connection ring 684 (see Fig. 25). The operator
24 output connection ring is secured by fasteners to the output shafts of

1 pneumatic actuator engines 691. Fig. 25 also shows pneumatic manifolds
2 692 used to supply the actuator engines. The preferred construction
3 shows three actuator engines 691 which have outputs which move
4 upwardly and downwardly to depress the transmission heads 658 and
5 operate the fingers in the compound axial and pivotal motion already
6 described. The actuator engine outputs are extended to depress rings
7 683 and 684, and to depress the transmission heads 658 thus causing
8 the fingers 979 to move from the inboard retracted positions of Fig. 28
9 to the outboard extended positions of Fig. 27.

11 Electrode Fingers With Submerged Conductive Current Transfer Areas

12 Figs. 32-39 show a number of different electrode finger
13 constructions. The different constructions shown have particular
14 application to differing applications. Fig. 32 shows a finger assembly
15 631 having intended application for contacting a semiconductor wafer
16 during blanket plating of copper. Finger assembly 631 includes a finger
17 shaft 632 which is formed in a J-shape and made from an electrically
18 conductive material, such as stainless steel or tungsten. The finger
19 assembly also preferably includes an integral finger head 633 which is
20 received into the receptacle 954 of the actuator transmission 960. The
21 head has a pin aperture which receives the locking pin 956 therein for
22 engagement with the locking groove 955 formed in the receptacle of the
23 actuator transmission.

1 Finger assembly 631 also preferably includes dielectric sheathing
2 634 and 635. Dielectric sheathing 634 and 635 is advantageously made
3 from a polyvinylidene fluoride coating or layer applied to the shaft of
4 the finger. The dielectric sheathing is preferably provided upon only
5 limited portions of the electrode shaft and adjacent the contact head
6 636. The contact head has a contact face 637 which directly bears
7 upon the wafer to pass electrical current between the electrode and
8 wafer. The contact face 637 is approximately equal to a fluid
9 submersion boundary 639. The submersion boundary indicates the
10 approximate level of the plating liquid during processing.

11 The limited coverage of the dielectric sheathing is for the purpose
12 of improving the uniformity of plating performed upon semiconductor
13 workpieces held in the wafer support. It is believed that the
14 submersible surfaces of the electrode finger are best provided with
15 dielectric sheathing segments which comprise between approximately 25
16 percent and 75 percent of the submersible area of the electrode.
17 These amounts do not consider the contact face as part of the areas.
18 Fig. 32 show two segments 634 and 635 which cover about 50 percent
19 of the electrode finger shaft exterior surfaces from the submersion line
20 639 downward, as positioned in a plating liquid bath during processing.
21 The first dielectric segment 634 is adjacent to the contact face 637.
22 a first electrically conductive segment 642 exists between the dielectric
23 segment 634 and the contact face 637. A second electrically conductive
24 segment 643 exists between first and second dielectric segments 634 and

635. A third electrically conductive segment 644 exists between the second dielectric segment 635 and submersion line 639. The electrically conductive segments 642-644 provide current transfer areas which cause plating current that is supplied through the finger head 633 to be directly passed to the plating liquid contained in a plating bath. This is believed to provide a more uniform current density and more uniform voltage profile across the surface of a wafer which is being blanket plated with copper or other plating metals.

Fig. 33 shows another plating system workpiece support electrode 651 having many of the same features as electrode 631 described immediately above. The same reference numerals have been used to designate similar parts. Differences between finger electrodes 651 and 631 will now be described. Electrode 651 has three current transfer areas 642-644. The size and shape of areas 642-644 are somewhat different from the corresponding areas of electrode 631. More specifically, the second and third current transfer areas 643 and 644 are elongated along the shaft. The second dielectric sheath segment 635 is shortened. A third dielectric segment 653 has been included. The third dielectric sheath 654 forms the submerged dielectric segment 653 and also extends above the submersion line 639 to head 633. The area of the submerged current transfer segments is between 25 and 75 percent of the submerged surface area, more particularly, about 50 percent.

1 Electrode 651 is also provided with a distal contact insert part
2 655. Insert part 655 is received within an insert receptacle 616 formed
3 in the distal end of the electrode shaft. The insert contact tip 655
4 defines a contact face 617 which bears upon a wafer being held. The
5 insert contact part is made from a conductive material which is
6 preferably non-corrosive material, such as platinum or stainless steel.

7 Fig. 34 shows a further electrode finger construction in the form
8 of electrode finger 979. Similar parts to electrode fingers 631 and 651
9 are similarly numbered in this figure. The electrode shaft is covered
10 by a dielectric sheath 621 which largely covers the electrode shaft and
11 leaves only a first current conductive area 642 which is immediately
12 adjacent to the contact face 637. This construction is contrasted to the
13 electrodes 631 and 651 because electrode finger 979 does not have
14 current transfer areas which comprise 25 percent of the submerged
15 portion of the electrode. It also does not have current transfer areas
16 which are exposed in a manner which is separated by a dielectric
17 segment interpositioned between the contact face 637 and the removed
18 or remote current conductive segment.

19 Fig. 35 shows a further electrode finger 601 which has submerged
20 current transfer areas 642-644. It also has dielectric segments 634 and
21 635. Dielectric segment 635 of this figure has a differing shape and
22 coverage area as compared to the other electrodes discussed above. In
23 this construction the dielectric sheath extends along the outer curvature
24 of the electrode J-bend. Curved upper edges extend so as to provide

1 an overlying web portion 603 which covers the inner curvature of the
2 J-bend. Performance in terms of plating uniformity has been found to
3 be superior in some processes which employed the electrode of this
4 figure.

5 . The electrodes 631, 651 and 601 are preferably used in novel
6 processes according to this invention. These processes include contacting
7 a surface of the semiconductor article or workpiece with an electrode
8 at a contact face thereof. The methods also include submersing a
9 portion or portions of the electrode into a plating bath containing a
10 plating liquid which is typically a solution and mixture have various
11 components known in the art. The methods also preferably include
12 wetting a processed surface of the semiconductor article with the plating
13 bath. Further included is the step of moving or conducting electrical
14 current through the electrode and plating bath to perform an
15 electroplating action to occur upon at least the processed surface of the
16 wafer or other article. The methods further advantageously include
17 diverting a portion of the electrical current directly between the
18 electrode and the plating bath along at least one electrically conductive
19 segment of the electrode. The electrically conductive segment is
20 preferably spaced from the contact face a substantial distance, such as
21 greater than 5 millimeters, and preferably is spaced therefrom by an
22 intervening dielectric sheath.

Electrode Fingers With Dielectric Sheaths Covering Submerged Areas

Fig. 36 shows another electrode finger 681 which is similar to electrode finger 651. Finger 681 is similar to finger 651 except it includes a full dielectric sheath 682 which extends from above submersion line 639 to contact insert side walls 619. This construction preferably uses a coating layer 682, such as from polyvinylidene fluoride, which can be applied by dipping or otherwise forming the layer over the shaft of the electrode. This construction includes the dielectric layer over the distal end of the electrode shaft and into sealing relationship with the side walls of the insert contact part or tip 655. The dielectric coating or other layer 682 excludes corrosive processing fluids. Since the contact tip is preferably made from a non-corrosive material, such as platinum, the only material of the electrode which is exposed to direct corrosive action is the non-corrosive tip which is able to maintain good service despite the difficult operating environment.

Additionally, the construction of electrode 681 is particularly advantageous because the joint formed between the inserted contact tip 655 and receptacle 616 is covered and protected from direct exposure to the corrosive plating liquid and fumes present in the processing chamber.

The invention further includes methods for plating metals onto the surface of a semiconductor workpiece using electrode finger 681. The methods include contacting a surface of the workpiece with an electrode assembly using a contact face, such as face 617, on a contact part, such

as contact insert part 655. The contact insert is mounted on the distal end of the electrode shaft. It is further preferably provided with a dielectric layer formed about the distal end in sealing relationship against the contact part. The methods further preferably include submersing or otherwise wetting a processed surface of the workpiece, such as in a plating bath liquid used to plate the workpiece with a plating material. The methods also preferably include excluding the plating bath liquified from the contact part joint, such as the joint formed between the contact part 655 and receptacle 616. The methods further include electroplating the workpiece with plating material by passing electrical current through the contact part and between the semiconductor workpiece and electrode assembly. The contact face plating layer is more preferably formed from the plating material as is described below in additional detail. The method is most preferably used to plate copper onto the surface of semiconductor materials, such as silicon or oxides thereof.

Pre-Conditioning of Electrode Contact Faces

Figs. 37 and 38 illustrates a further electrode construction in accordance with further inventive aspects of the workpiece support systems and methods described herein. Fig. 37 shows distal end portions of an electrode 614. Electrode 614 is otherwise similar to electrode 681 described above. At the distal end of electrode finger 614 is a distal exposed surface 615 is made from a suitable material,

1 such as stainless steel or tungsten. A dielectric sheath 616 is
2 advantageously provided along the exterior portions of the electrode
3 adjacent to the distal exposed surface 615.

4 Fig. 38 shows the electrode 614 with a deposited contact face
5 plating layer 618 formed thereon. The layer 618 is preferably a layer
6 made from the same or a very similar material as is being plated onto
7 the semiconductor workpieces with which electrode 614 is to be used.
8 For example, if copper is being plated onto the semiconductor device,
9 then the layer 618 is a layer plated from the same plating bath or
10 from a plating bath which will provide a layer 618 which is the same
11 or very similar to the constituency of the copper deposited onto the
12 semiconductor device being plated. In a preferred manner of carrying
13 out this invention, the exposed distal surfaces 615 are placed into a
14 plating bath and electrical current is conducted through the bath and
15 distal end of the electrode 614. This causes a plating action to occur
16 which deposits the layer 618. The resulting layer is preferably at least
17 1 micron in thickness, more preferably in the approximate range of 1-
18 100 microns thick.

19 This method and resulting construction results in a pre-conditioned
20 electrode contact surface which is of the same or very similar material
21 as plated onto the semiconductor device during the later plating
22 operation. The use of the same or similar materials prevents galvanic
23 or other types of chemical reactions from developing due to dissimilarity
24 of the metals involved.

The invention further includes additional methods for plating metals onto the surface of a semiconductor workpiece. The preferred methods include contacting a surface of the semiconductor workpiece with an electrode at a contact face forming a part of the electrode. The contact face is covered or substantially covered by a contact face plating layer. The contact face plating layer is formed from a contact face plating material which is the same or chemically similar to the plating material which is to be plated onto the semiconductor workpiece during processing. The methods also preferably include submersing or otherwise wetting a processed surface of the workpiece into a plating bath or using a plating liquid or fluid. Other means for depositing the plating material as a contact face layer may alternatively be used. The methods further include electroplating workpiece plating material onto the semiconductor workpiece by passing electrical current between the workpiece and the electrode having such contact face plating layer. The methods are of particular advantage in the plating of copper onto semiconductors using a copper contact face plating layer.

Methods Using Workpiece-Engaging Electrode Assembly With Sealing Boot

Fig. 39 shows a further electrode finger 583 which has features similar to 651 and such similar features are identified with the same reference numbers. Electrode finger 583 differs from finger 651 in that the electrode shaft 584 is covered between the head 633 to the distal end of the electrode shaft with a cover or boot 585. Boot 585 is

1 preferably made in a manner which provides a continuous cover from
2 near the electrode head 633 to a distal contact lip 586. The boot
3 includes additional features adjacent the contact insert part 655. More
4 specifically, the boot includes a skirt portion 587 which extends above
5 the electrode shaft distal end surface 588. The contact face 617 of the
6 insert part 655 is preferably about even with the distal contact lip 586
7 which is formed upon the end of the skirt portion 587. The skirt
8 portion serves as a deformable seal which comes into contact with a
9 surface of a wafer or other semiconductor workpiece being contacted.

10 Figs. 40 and 41 illustrate novel methods which advantageously
11 utilize the improved features of electrode finger 583. The methods
12 involve plating metals onto the surface of semiconductor workpieces,
13 specifically onto a semiconductor wafer W which has a substrate or
14 other subjacent layer 561 which has been previously provided with a
15 thin metallic seed layer 562 which is shown by a heavy black line in
16 that figure. A via or other opening 563 exists in a photoresist layer
17 564 which overlies the substrate and seed layers.

18 Fig. 40 shows the electrode 583 poised in a disengaged position
19 in preparation for contact with the surface. Fig. 41 shows the electrode
20 583 retracted against the surface of the workpiece. In the engaged
21 position the contact face 617 is extended through the opening 563 and
22 into direct electrical contact with exposed areas of the seed layer 562
23 which are not covered by the layer of photoresist or other covering
24

1 layer. A seal is formed by depressing the skirt 587 and attached lip
2 586 against the outer surface of the photoresist layer 564.

3 The novel methods include selecting an electrode assembly having
4 desired features, such the features of electrode finger 583. More
5 specifically, the selecting step preferably includes selecting an electrode
6 assembly having an electrode contact which is surrounded by an
7 electrode boot or other sealing member. The methods also include
8 engaging coated surface portions, such as photoresist layer 564, with the
9 sealing member or boot. The sealing can occur about a continuous
10 peripheral sealing line, such as defined by the engagement of lip 586
11 against the photoresist surface. It is important to engage the lip
12 against the photoresist surface and not against the seed layer 562
13 because sealing against the seed layer can cause erosive or corrosive
14 effects to occur at or near the line or area of engagement of the boot
15 with the seed layer. Such erosive or corrosive actions can cause the
16 seed layer to become discontinuous or even totally isolated. A
17 discontinuous or isolated contact region will lead to electroplating failure
18 because the needed current will not be communicated in an even
19 manner to the areas adjacent to the electrode which need current to
20 accomplish plating. The engagement of the seal against the coating
21 causes a sealed space to be enclosed within the seal by the electrode
22 boot and the processed surface of the workpiece.

23 The novel methods further include enclosing a via or other
24 opening within the seal. The via is present on the processed surface

and has associated exposed seed layer portions therein for allowing electrical contact to be made. The via is needed to allow direct contact between the contact face of the electrode finger assembly and the seed layer which is used to communicate electrical current across the wafer for electroplating a metal thereonto. Thus, the methods further include contacting the seed layer through the via with the electrode contact to form an electrically conductive connection between the electrode assembly and the seed layer. This contacting step is advantageously performed using a contact face which bears upon the seed layer and is enclosed with the sealed space. Other desirable attributes explained hereinabove in connection with other electrodes can also be utilized to advantage in performing this process.

The methods still further include wetting the processed surface of the workpiece with a plating or other processing liquid. This is typically done by lowering the wafer holder into position to bring the outer, processed surface of the wafer into direct contact with a plating liquid held in a plating bath, such as described elsewhere herein in additional detail.

The methods also preferably include passing electrical current through the electrode and plating bath to cause electroplating to occur upon exposed seed layer areas of the processed surface. Such exposed seed layer areas may be trenches, vias or other features where the photoresist layer 564 is not present to cover the seed layer 562. The

1 electrical current causes electroplating to occur on such exposed seed
2 layer areas.

3 Still further, the methods preferably include excluding plating or
4 other processing liquid from the sealed space to substantially reduce or
5 eliminate plating or other action in the area immediate adjacent to the
6 contact with the electrode.

7 The methods described above are of particular relevance to plating
8 copper onto semiconductors.

9 10 **Plating Bowl Assembly**

11 Fig. 42 shows an electroplating bowl assembly 303. The process
12 bowl assembly consists of a process bowl or plating vessel 316 having
13 an outer bowl side wall 617, bowl bottom 319, and bowl rim assembly
14 314. The process bowl is preferably circular in horizontal cross-section
15 and generally cylindrical in shape although other shapes of process bowl
16 may be possible.

17 The invention further advantageously includes a cup assembly 320
18 which is disposed within process bowl vessel 316. Cup assembly 320
19 includes a fluid cup portion 321 having a cup side 322 and a cup
20 bottom 323. As with the outer process bowl, the fluid cup 321 is
21 preferably circular in horizontal cross-section and cylindrical in shape.
22 The cup assembly also has a depending skirt 371 which extends below
23 the cup bottom 323 and has flutes 372 open therethrough for fluid
24 communication and release of any gas that might collect as the chamber

below fills with liquid. The cup assembly can be made using upper and lower portions which couple together at a cup main joint 387. The cup is preferably made from polypropylene or other suitable material, which is advantageously dielectric.

The lower opening in the cup bottom wall is connected to a riser tube 361 which is adjustable in height relative thereto by a threaded connection. The riser tube seals between the bottom wall 319 of the process bowl and the cup bottom 323. The riser tube is preferably made from polypropylene or other suitable dielectric material. A fitting 362 connects the riser tube 361 and the fluid inlet line 325 to allow adjustment of the anode vertical position. The fitting 362 can accommodate height adjustment of both the riser tube and inlet line 325. The inlet line is made from a conductive material, such as titanium and is used to conduct electrical current to the anode 324, as well as supply fluid to the cup.

Process fluid is provided to the cup through fluid inlet line 325. The fluid inlet line rises through riser tube 361 and bowl bottom opening 327 and through cup fluid inlet openings 324. Plating fluid fills the cup portion 321 through opening 324 as supplied by a plating fluid pump (not shown) or other suitable supply which provides the fluid under at least some pressure for delivery.

The upper edge of the cup side wall 322 forms a weir which determines the level of plating liquid within the cup. Excess fluid pours over this top edge surface into the overflow chamber 345. The

fluid held in the overflow chamber 345 is sensed by two level detectors 351 and 352. One level detector is used to sense a desired high level and the other is used to sense an overfull condition. The level of liquid is preferably maintained within a desired range for stability of operation. This can be done using several different outflow configurations. A preferred configuration is to sense the high level using detector 351 and then drain fluid through a drain line as controlled by a control valve. It is also possible to use a standpipe arrangement (not illustrate), and such is used as a final overflow protection device in the preferred plating station 303. More complex level controls are also possible.

The outflow liquid from chamber 345 is preferably returned to a suitable reservoir. The liquid can then be treated with additional plating chemicals or other constituents of the plating or other process liquid and used again.

The plating bowl assembly 303 further includes an anode 334. In the preferred uses according to this invention, the anode is a consumable anode used in connection with the plating of copper or other metals onto semiconductor materials. The specific anode will vary depending upon the metal being plated and other specifics of the plating liquid being used. A number of different consumable anodes which are commercially available may be used as anode 334.

Fig. 42 also shows a diffusion plate 375 provide above the anode 334 for rendering the fluid plating bath above the diffusion plate with

less turbulence. Fluid passages are provided over all or a portion of the diffusion plate to allow fluid communication therethrough. The height of the diffusion plate is adjustable using three diffuser height adjustment mechanisms 386 and secured by three mounting fasteners 389.

Plating Anode Shield

The invention also includes an anode shield 393 which can be secured to the consumable anode 334 using anode shield fasteners 394. The anode shield and anode shield fasteners are preferably made from a dielectric material, such as polyvinylidene fluoride or polypropylene. The anode shield is advantageously about 2-5 millimeters thick, more preferably about 3 millimeters thick.

The anode shield serves to electrically isolate and physically protect the back side of the anode. It also reduces the consumption of organic plating liquid additives consumed. Although the exact mechanism may not be known at this time, the anode shield is believed to prevent disruption of certain materials which develop over time on the back side of the anode. If the anode is left unshielded the organic chemical plating additives are consumed at a significantly greater rate. With the shield in place these additive are consumed less. The shield is preferably positioned on the anode so as to shield it from direct impingement by the incoming plating liquid.

1 The invention thus also include methods for plating which include
2 other method steps described herein in combination with shielding a
3 consumable anode from direct flow of plating liquids using a dielectric
4 anode shield.

5
6 In compliance with the statute, the invention has been described
7 in language more or less specific as to structural and methodical
8 features. It is to be understood, however, that the invention is not
9 limited to the specific features shown and described, since the means
10 herein disclosed comprise preferred forms of putting the invention into
11 effect. The invention is, therefore, claimed in any of its forms or
12 modifications within the proper scope of the appended claims
13 appropriately interpreted in accordance with the doctrine of equivalents.
14
15
16
17
18
19
20
21
22
23
24